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Investigation 10: Energy Dynamics

Adapted from Bill Wesley, Mars Area High School

Lab Overview

In this lab, students are to create a MODEL ecosystem to estimate the **Net Primary Productivity (NPP)** of plants grown under light and the FLOW of energy from the plants to white butterfly larvae (the consumers) as they eat the plants, grow, and release feces. As we have studied, the energy dynamics of an ecosystem can be accounted for by the energy coming in (input) and going out (output) through different members of the community. The lab is set up in two parts:

<u>Part 1</u>

Estimate primary productivity of some fast growing plant in the family of Brussels sprouts.

- You would grow a sufficient number of plants so that you could remove 10 plants, root included (dirt removed) at 1 week, and again at 2 weeks. You would weigh them **<u>wet</u>**, then dry in an oven, and weigh again **<u>dry</u>** to determine their true Biomass DRY without the extra water.
- Using this data, you would calculate their **% biomass (dry/wet x 100%)** and their **NPP** (**net primary production**) per day per plant (explained later).
  - Note: This estimated % biomass data from *Part 1* is needed at the end of *Part 2* to estimate the biomass of Brussels sprouts.
  - Given a lot more time, one could have grown the Brussels sprouts themselves to determine their true NPP. Growing the fast plants relatives of Brussel sprouts enables us to determine an approximate NPP for Brussels sprouts much quicker.

<u>Part 2</u>

Estimate energy flow between fast plant producers and cabbage butterfly larvae.

- A Brussels sprout (a relative of the Fast plants) is weighed, cut in 1/2, and then placed in a "plant barn".
- Students then weigh ten 12-day old cabbage butterfly larvae as a group and determine the mean mass per individual larva. These 10 larvae are added to the barn.
- Students collect, dry, and weigh the frass (fecal material) produced by the larvae over the next **three** days. After three days of feeding, they weigh the 15-day old larvae as a group again, and determine the mean mass per individual.
- Finally, students weigh the remaining part of the Brussels sprout and determine the amount of Brussels sprout biomass consumed by each larva per day.

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Review

Now that you understand the basic flow of the lab, let's review some concepts being reinforced by this lab, learn how to perform the math calculations, and draw appropriate conclusions so as to prepare for the AP Bio National Exam:

1. Define the following:
    - Primary production
    - Net primary production (NPP)
    - Secondary production
    - Production efficiency
    - Trophic efficiency

2. Write out the formula for ***photosynthesis:***

3. ***Primary Productivity*** is the RATE that energy is captured by photosynthetic organisms and converted into organic molecules (glucose) in a given area per unit of time. In other words, it is the RATE of photosynthesis. What are three ways we can measure ***Primary Productivity?*** (*Hint: Use the formula as reference. Note that water produced is usually not a reliable measurement, because at any given time, there may be more or less environmental water/moisture beyond the water created via photosynthesis!)*
    -
    -
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Reasoning behind Procedure and Math

Recall that in our photosynthesis and respiration labs, we focused on the rate of *oxygen production/consumption* using an apparatus submerged in water. Measuring the *dissolved oxygen produced* is also an easy, appropriate way to measure productivity in an aquatic system. However, for a terrestrial system such as caterpillars eating plants, *biomass produced* is a more appropriate method. The organic molecules created through photosynthesis have MASS, so the energy in biological systems can be indirectly measured by mass. **Remember – BIOMASS is always measured DRY!**

4. Why is drying necessary? Explain

5. What would be a problem if we were to measure the true biomass (DRY!) of the caterpillars as they grow?

6. Besides the new growth in biomass, what else would we have to measure from the **caterpillar** (our primary Consumer)? Why?

Because we cannot weigh the true Biomass DRY of the larvae, the following is given to you: ***The Biomass DRY = about <u>40%</u> of the measured "wet" weight***

<u>Sample calculation:</u> 10g caterpillars → Biomass DRY = 10g x 40% = 10g x 0.4 = 4g
So 10g caterpillars = approx. 4g Biomass DRY

Now, can we track **energy flow** with our biomass measurements? We would need to use a calorimeter, burn the dry biomass, and measure the **kcal released** for the plant and caterpillar. Instead of going through that process, researchers have already determined the average kcal per gram for the plant, caterpillar, and caterpillar frass. These are **given** as follows:

Each **gram** of **plant biomass** = about **4.35 kcal/g** of energy
Each **gram** of **butterfly larvae** = about **5.5 kcal/g** of energy
Each **gram** of **butterfly larvae frass** = about **4.76 kcal/g** of energy

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Sample calculation problem: If **10** caterpillars (larvae) were weighed at **3.0g total**, approximately how much **energy (kcal)** would the biomass DRY of a **single** larvae represent?

Answer →

Calc avg mass of one larvae - 3.0g total caterpillar mass / 10 caterpillars = **0.3g per caterpillar**
Calc avg Biomass DRY - 0.3g caterpillar x 40% (0.4) = **0.12g Biomass DRY per caterpillar**
Calc avg energy(kcal) produced per gram Biomass DRY –
0.12g Biomass DRY per caterpillar x 5.5kcal/g = **0.66kcal per caterpillar**

Practice problems:

- If **20** caterpillars were weighed at **8.0g total**, approximately how much **energy (kcal)** would the biomass DRY of a **single** larvae represent?

Show ALL work and units!

- If **2** caterpillars were weighed at **0.5g total**, approximately how much **energy (kcal)** would the biomass DRY of a **single** larvae represent?

Show ALL work and units!

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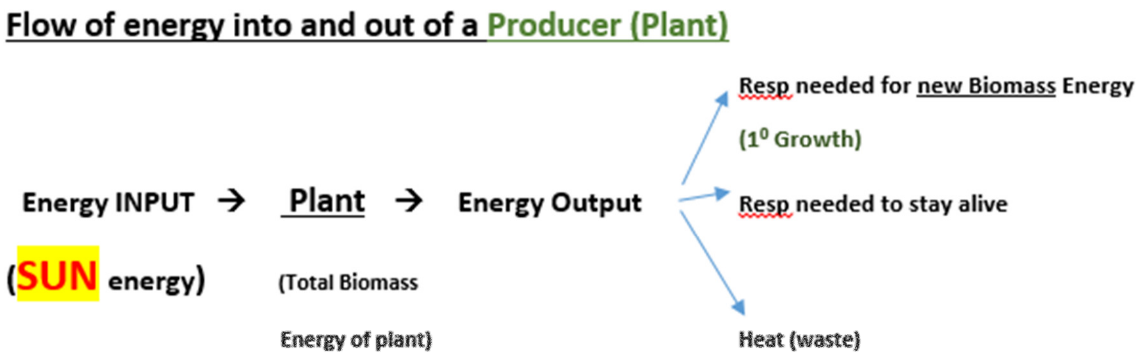
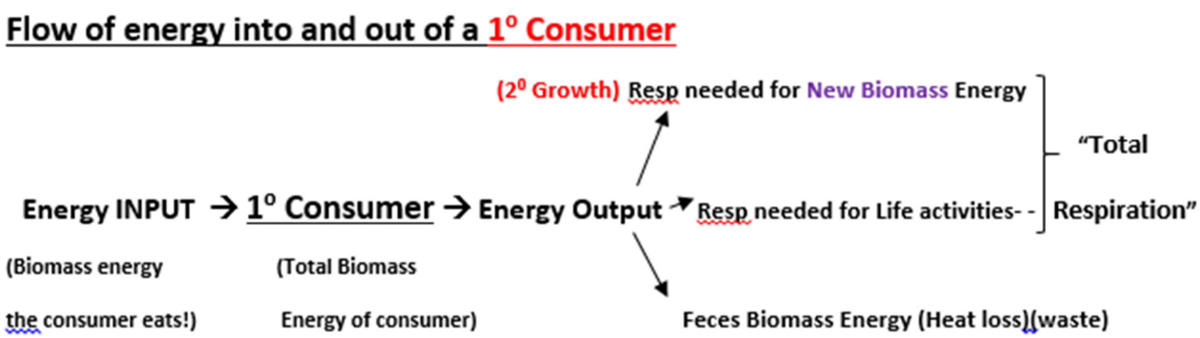
Energy Input and Output

Now, carefully review the models of energy flow below, and then answer the questions.





7. From where does the energy input for producers come?

8. In the **producer model**, which output represents the energy available to *Primary Consumers*?

9. What measurement in this lab reflects this?

10. In the **primary consumer model**, which output represents the energy available to *Secondary Consumers*?

11. Which two of the three outputs of the *Primary Consumer* can we directly measure?

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Sample Data

Here's some sample data and calculations collected by students performing this lab.

Fill in the blank boxes.

Sample Fast Plant Data

Plant Age	"Wet" Mass of 10 Plants	"Dry" Biomass of 10 Plants	Percent Biomass (dry/wet)	Energy in 10 Plants (Dry Biomass x 4.35 kcal)	NPP per day per plant
7 days	20.1 grams	4.4 grams	%	kcal	kcal/day
14 days	38.9 grams	9.4 grams	%	kcal	kcal/day

12. What is the average percent biomass from the chart above? Show calculation work!

*****This is really important – we will use this to approximate the dry mass of the Brussels sprouts eaten by the caterpillars in the next chart!!***

13. Show the math calculation used to get the NPP per day per plant for the 7-day old plant

14. What is the average energy these plants are able to pass on to the next trophic level (Primary Consumers)? (Round to the nearest tenth)

15. Draw an **energy pyramid** representing the ecosystem in this lab.

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Carefully review the mock data below. Then complete the calculations and answer the following questions.

Sample Brussels Sprouts and Caterpillar Data

Larvae Age	**Day 1** (12-day old larvae)	**Day 3** (15-day old larvae)	**Over 3 Days of Growth**
1. Mass of Brussels Sprouts	31 g	11 g	g (total mass consumed)
2. Dry Mass of Brussels sprouts (mass x 23%) (23% is the average % biomass from fast plant data table)	g	g	g (total mass consumed)
3. Plant Energy (biomass x 4.35 kcal/g)	kcal	kcal	kcal
4. Plant Energy Consumed by each Larva (plant energy/10)	kcal	kcal	kcal per larva
5. Mass of 10 Larvae	0.4 g	2.0 g	g (gained)
6. Average Mass of one Larva	g	g	g (gained)
7. Larva percent biomass (as stated in lab manual)	40%	40%	40%
8. Individual larva biomass (mass x % biomass)	g	g	g (gained)
9. Energy produced per individual (New Growth) (individual biomass x 5.5 kcal/g)	kcal	kcal	kcal
10. Mass of the frass from all larvae		0.4 g	0.4 g (excreted)
11. Frass per individual		g	g (excreted)
12. Waste energy (frass mass x 4.76 kcal/g)		kcal	kcal (excreted)
13. ***Estimate*** of Total Cellular Respiration (plant energy consumed – waste energy produced)			kcal

16. Which row represents the energy INPUT to the caterpillar in the Primary Consumer model? What is the value? **(Include units!)**

17. Which row represents the Respiration energy needed for **New biomass** in the Primary Consumer model? What is the value? **(Include units!)**

18. Which row represents the Feces Biomass energy in the Primary Consumer model? What is the value? **(Include units!)**

19. Which row represents the total respiration for **Life activities** and **New Biomass**? What is the value? **(Include units!)** (HINT: Refer back to the primary consumer flow chart)

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Final Calculation

20. How much energy is needed by one caterpillar for respiration just to stay alive (life activities)?
    - Fill in the flow chart below using your values (with units) from questions 16-19 to help you visualize the math
    - Apply the information from the "Flow of Energy into and out of a Primary Consumer" model to help you
    - Show your calculations

INPUT _______ → **Primary Consumer** → OUTPUT → __________ / __________ / __________ } ______

Calculations:

Final Answer:

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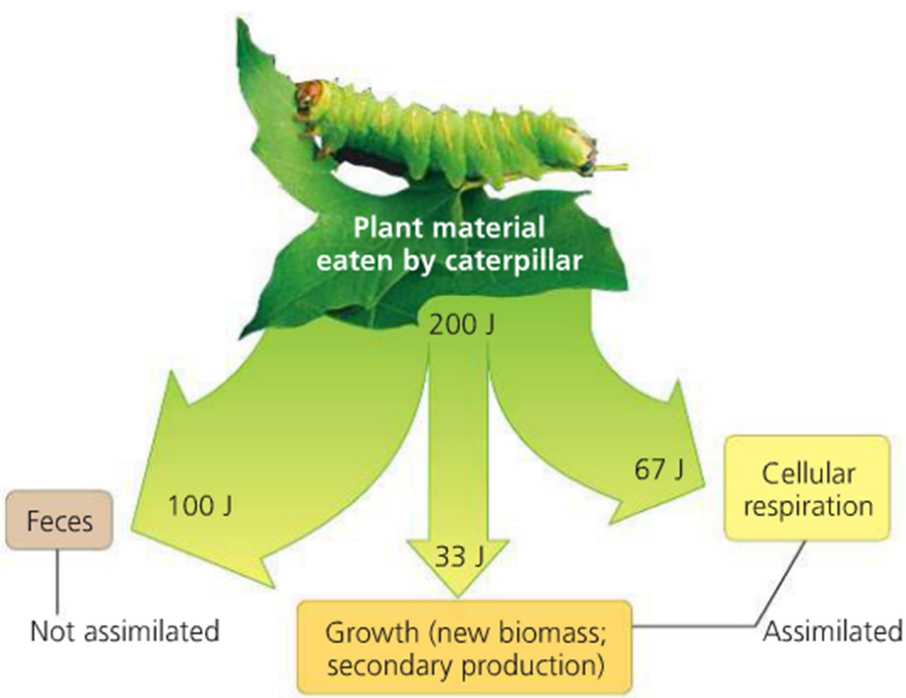
Production Efficiency

What do these numbers have to do with production efficiencies? Recall that *net secondary production* is the energy stored in biomass represented by growth and reproduction. *Assimilation* consists of the total energy taken in used for growth, reproduction, and respiration, NOT including losses in feces. Applying the categories used in the sample data, net secondary production is the "New Biomass" value while assimilation is the "TOTAL Respiration" that includes the respiration values for BOTH "Life Activities" AND "New Biomass."

Production efficiency, therefore, is the percentage of energy stored in assimilated food that is not used in respiration. In other words, production efficiency is the percentage of energy converted into new growth from what was assimilated (and does NOT include energy lost as heat or in feces). To calculate production efficiency,

1. Find the net secondary production
   - Subtract the energy eliminated in feces and the energy used in cellular respiration from the total energy consumed to get the net secondary production
2. Calculate the assimilated energy
   - Add the net secondary production you just calculated to the energy used for respiration
3. Determine production efficiency
   - Divide the net secondary production by assimilated energy



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<u>Sample calculation problem</u>: A caterpillar eats 200 J of plant material. Of this, 100 J is indigestible and is eliminated as feces, and 67 J are used in cellular respiration. What is the approximate production efficiency of this animal?

Answer →

1. Find the net secondary production
    - Subtract the energy eliminated in feces and the energy used in cellular respiration from the total energy consumed to get the net secondary production
    - 200 J – 100 J – 67 J = 33 J = net secondary production
2. Calculate the assimilated energy
    - Add the net secondary production you just calculated to the energy used for respiration
    - 33 J + 67 J = 100 J = assimilated energy
3. Determine production efficiency
    - Divide the net secondary production by assimilated energy
    - 33 J / 100 J = 0.33 = **33% production efficiency**

<u>Practice problems</u>:

- If an insect that eats plant seeds containing 100 J of energy uses 30 J of that energy for respiration and excretes 50 J in its feces, what is the insect's net secondary production? What is its production efficiency? ***Show ALL work and units!***

- A porcupine eats 3,000 J of plant material. Of this, 2,100 J is indigestible and is eliminated as feces, 800 J are used in cellular respiration, and 100 J are used for growth and reproduction. What is the approximate production efficiency of this animal? ***Show ALL work and units!***

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Trophic Efficiency

Trophic efficiencies are always less than production efficiencies because they take into account not only the energy lost through respiration and contained in fees, but also the energy in organic material in a lower trophic level that is not consumed by the next trophic level. Trophic efficiencies are generally only about 10%. In other words, 90% of the energy available at one trophic level typically is *not* transferred to the next. This loss is multiplied over the length of a food chain.

For example, if 10% of available energy is transferred from primary producers to primary consumers (such as caterpillars), and 10% of that energy is transferred to secondary consumers (called carnivores), then only 1% of net primary production is available to secondary consumers (10% of 10%). The progressive loss of energy along a food chain severely limits the abundance of top-level carnivores that an ecosystem can support. Only about 0.1% of the chemical energy fixed by photosynthesis can flow all the way through a food web to a tertiary consumer (such as a snake or a shark). This explains why most food webs include only about four or five trophic levels.

Sample calculation problem:

Consider the following food chain: Brussel sprouts → caterpillar → warbler → snake → eagle. How much of the chemical energy fixed by photosynthesis of the Brussel sprouts (100%) is available to each of the other organisms in the food chain?

Answer →

- Caterpillar: 100% x 0.1 = 10%
- Warbler: 10% x 0.1 = 1%
- Snake: 1% x 0.1 = 0.1%
- Eagle: 0.1% x 0.1 = 0.01%

Practice problem:

- Approximately how many kg of herbivore biomass can be supported by a field plot containing 10,000 kg of plant material? Carnivore biomass?
  Show ALL work and units!